

Rehydration properties of hybrid method dried fruit enriched by natural components**

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Received March 23, 2017; accepted December 29, 2017

Abstract. The aim of the study was to determine the impact of osmotic pre-dehydration and drying of fruit on the rehydration properties of dried fruit. Herein, the effect of fruit juice, applied as a natural enriching substance was very important. In addition, the properties of dried fruits obtained through combined air-drying and subsequent microwave-vacuum drying with ‘puffing’ effect were similar to the freeze-dried fruits, but showed other rehydration properties. As raw material, frozen strawberry (Honeoye variety) and fresh apples (Idared variety) were used in the study. The apples and partially defrosted strawberries were prior dehydrated in solutions of sucrose and a mixture of sucrose with chokeberry juice concentrate at 50°C for 2 h. Next, the fruit samples were dried by one of two ways: air-drying (50°C, 5 h) and microwave-vacuum drying for about 360 s; and freeze-drying (30°C, 63 Pa, 24 h). The rehydration was carried out in distilled water (20°C, 5 h). The osmotic pre-dehydration hindered fruit drying process. The impact of drying method became particularly evident while examining the kinetics of rehydration. During the rehydration of the pre-dehydrated dried fruit a slower hydration could be observed. Freeze-dried strawberries absorbed 2-3 times more water than those dried by the ‘puffing’ effect.

Keywords: apple, strawberry, chokeberry juice, puffing, PCA analysis

INTRODUCTION

An important indicator of quality of dried material is its rehydration capability (Figiel, 2007). The rehydration of plant tissue is directly related to the method used for

obtaining the dried fruit. This, after the process, does not display the same features as the raw material (Kaleta *et al.*, 2008). The methods of removing water from food result in a variety of changes in the tissue which impairs the possibility for regaining volume, mass and water content. Only freeze-drying allows a water removal at low temperature. It protects the primary structure and the shape of the products, with minimal volume reduction (Ratti, 2001). However, it takes a long time and is not economical. An alternative process is the convection-microwave-vacuum drying technique with ‘puffing’ effect (hybrid way), which significantly reduces the drying time, and the drought properties are similar to freeze-drying (Figiel, 2010).

Osmotic dehydration promotes a decrease in water content of raw material that makes it a suitable process for the producing of safe products with intermediate water content (Cheng *et al.*, 2014). As holding the potential to obtain better food products by removing water at low temperature, it has been widely used as a pre-treatment step in the food drying process since it can reduce the overall energy requirement for further drying process (Akbarian *et al.*, 2014; Bruijn and Bórquez, 2014; Chandra and Kumari, 2015; Mauro *et al.*, 2016; Nuñez-Mancilla *et al.*, 2013; Yadav and Singh, 2012). Besides the sugar infusion, other natural biocomponents, *e.g.* those naturally present in a fruit juice concentrate, penetrate the dehydrated fruits. Both the sugar and these substances affect the water activity in the material. However, osmosis often increases the mechanical resistance of the tissue, and therefore, the initial dewatering can positively influence the process of drying and rehydration.

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**This work was financially supported by SUSFOOD ERA-Net/NCBiR (National Centre for Research and Development); project No. 5/SH/SUSFOOD1/2014. Implementation period: 2014-2016, Poland. The work was also co-financed by a statutory activity subsidy from the Polish Ministry of Science and Higher Education for the Faculty of Food Sciences of the Warsaw University of Life Sciences.

The aim of the study was to achieve an attractive product through pre-dehydration and simultaneous enrichment of apple and strawberry samples utilising chokeberry concentrate ingredients, and then drying the material by the convection-microwave-vacuum method (a hybrid approach). The properties of the indicated dried product were compared with the osmotic freeze-dried fruit.

MATERIALS AND METHODS

The research material was constituted of strawberry halves of the *Honeoye* variety having the diameter of about 3 cm, as well as apples of the *Idared* variety cut into 15x10 mm rings. The fresh strawberries were frozen at the temperature of -40°C for 2 h and then stored at the temperature of -20°C. The apples were stored in a refrigerator at the temperature of approx. 5°C. The apples and partially defrosted strawberries (for about 15 min) were dehydrated in solutions with a concentration of about 60%. Sucrose solution (SA) and a mixture at the ratio of 1:4 of sucrose and chokeberry *Aronia melanocarpa* juice concentrate (SA-CJC) of about 65° Brix were used for osmotic pre-treatment. The temperature of the process was 50°C and time 2 h. The convection drying was carried out at temperature of 50°C for 5 h. In order to obtain the effect of ‘puffing’, the fruit was dried in the microwave-vacuum drier (MVD) (the hybrid or ‘puffing’ effect) for about 6 min. Before freeze-drying (F-D), the samples were frozen at -40°C for 2 h and then dried at the temperature of heating shelves equal to 30°C under the pressure of 63 Pa for 24 h. The rehydration was carried out in distilled water having the temperature of 20°C and the range of 0-5 h. A two-factor analysis of variance ANOVA at two levels of volatility and a simple and multiple regression analysis were used for the evaluation of the obtained results (significance level 0.05). Principal component analysis (PCA) was also performed.

RESULTS AND DISCUSSION

Osmotic dehydration of apples and strawberries in solutions of sucrose and chokeberry juice concentrate (CJC) mixture resulted in a significantly higher (about 7-8%) mass loss compared to dehydration in sucrose solution without CJC (Table 1). Simultaneously, considerably higher, 19-20%, mass loss of strawberries was noticed in comparison with apples dewatered in the same osmotic solutions. Moreover, the statistical analysis showed the substantial impact of the type of raw material and osmotic substance on water loss and solid gain in the examined fruit. Compared to apples, greater mass loss of dehydrated strawberries results from approximately twice as high water loss. Moreover, smaller solid gain, in particular with the application of the sucrose with chokeberry concentrate solution, was seen. The ratio of water loss to solid gain (WL/SG) in dehydrated strawberries was also much higher, even three times more so, in comparison with the apples. Osmotic dehydration of fruit brought a decrease of moisture content in apples from 86.2 (in fresh) to 71-72% and from 91.1 (in frozen) to 75-78% in strawberries. Akbarian *et al.* (2014) showed that osmo-dehydrated products with removed 30 to 70% water were ready to use and can be consumed as shake ingredients or snack commodities. The addition of chokeberry concentrate to sucrose solution resulted in a lower moisture content, especially in strawberries. The better dewatering effect and lower solid gain related to fruit might have been the result of the higher molecular weight of the components contained in the solution with chokeberry concentrate addition, which found it more difficult to penetrate into the interior of the dehydrated tissue.

Osmotic pre-concentration is an effective way to reduce water content with minimal damage to fresh product quality (Akbarian *et al.*, 2014). In our work, the drying of fresh fruit resulted in a significantly bigger mass loss (86-90%)

Table 1. Moisture content (MC_{OD}), mass loss (ML_{OD}), water loss (WL), solids gain (SG) and the ratio of water loss to solid gain (WL/SG) in osmodehydrated apples and strawberries

Kind of osmotic substance	MC _{OD} (%)	ML _{OD} (%)	WL (g g ⁻¹ i. d.m.)	SG (g g ⁻¹ i. d.m.)	WL/SG
Apple					
–	86.2A ± 1.7	–	–	–	–
SA	72.0aB ± 2.4	22.28aA ± 1.36	2.19aA ± 0.07	0.58aA ± 0.03	3.8 ± 0.31
SA-CJC	71.2aB ± 1.4	30.31aB ± 2.39	2.65aA ± 0.09	0.44aA ± 0.05	6.0 ± 0.66
Strawberries					
–	91.1A ± 3.6	–	–	–	–
SA	78.5aB ± 2.5	41.92bA ± 2.15	4.40bA ± 0.19	0.50aA ± 0.02	10.6 ± 0.54
SA-CJC	74.8aB ± 1.8	49.16bB ± 2.69	5.15bA ± 0.21	0.30aA ± 0.05	18.2 ± 0.78

Homogeneous groups: a, b – type of fruit; A, B – type of osmotic substance.

in comparison with the use of the osmotic pre-treatment (69-88%) (Table 2). We did not observe any impact of the osmotic solution type in the osmotic pre-treatment on the mass loss of dried fruit. However, in most cases, the use of sucrose with chokeberry concentrate solution resulted in a slightly smaller mass loss than when a sucrose solution without CJC was used. Still, the osmotically pre-dehydrated dried apples were characterised by lower moisture content. In the case of the dried strawberries, the result was converse, but these were not statistically significant differences. We also found that dried fruit obtained by the same method, although, using a variety of osmo-active substances, presented very similar values of moisture content and mass loss. The indicators differed depending on the drying method. Similarly, the study conducted by Changure *et al.* (2008) revealed that the type of osmotic pre-treatment of strawberries did not affect the hybrid method of convection and vacuum-microwave drying. Simultaneously, it provided the possibility to obtain a higher quality product as far as the effects of rehydration were concerned. In addition, the studies conducted by Kowalski and Mierzwa (2013) showed that the osmotic pre-treatment of apples exerted only a slight effect on the kinetics of convective drying with microwave-vacuum drying. Despite the lower initial water content in osmo-dehydrated samples, the drying time

to reach the required water content and water activity was not significantly changed, and in most cases, was increased. With regard to low moisture content, the water activity (a_w) of the dried fruit was widely varied (0.22-0.63), however, this came about at a level which ensured their microbiological stability. In the case of the dried apples, a slightly lower water activity were noted in samples without the osmotic-treatment. The water activity of the freeze-dried fruit was within 0.22-0.26, whereas that of the dried by the convective drying with the 'puffing' effect was about 0.40. Therefore, the drying method had a significant effect on the water activity of both dried fruits. Strawberries revealed significantly higher water activity values, especially in the 'puffing' dried fruit (0.40-0.63).

At the beginning of the dried fruit rehydration, up to about 1 h, the mass gain (Δm) was the greatest (Fig. 1). The control droughts without pre-treatment showed higher rehydration ability than did the osmo-hybrid dried one. The mass gain kinetics of osmotically dehydrated and freeze-dried apples rehydration was similar to that of the 'puffing' dried fruit without the osmotic pretreatment. In the case of the dried strawberries, we observed a significant impact of the drying method on the kinetics of rehydration. Freeze-dried strawberries presented a 2-3 times greater capacity to absorb water when compared with the dried fruit obtained

Table 2. Moisture content (MC), mass loss (ML) and water activity (a_w) in dried apples and strawberries

Kind of osmotic substance	Drying methods	MC (%)	ML (%)	a_w (-)
Apple				
Raw material		5.52aBA ± 0.02	86.23 aBA ± 0.65	0.393aBA
SA	C-MVD	4.37 aBA ± 0.11	69.94 aBA ± 1.32	0.401aBA
SA-CJC		4.73 aBA ± 0.21	68.64aA±1.46	0.402aBA
Raw material		5.49 aAA ± 0.16	87.53 aBA ± 0.65	0.222aAA
SA	F-D	3.40 aAA ± 0.13	78.25 aBA ± 1.32	0.261aAA
SA-CJC		2.49 aAA ± 0.05	79.91 aBA ± 1.18	0.241aAA
Strawberries				
Raw material		3.06 aBA ± 0.22	89.93 aBA ± 0.92	0.631bBA
SA	C-MVD	4.10 aBA ± 0.13	78.59 aBA ± 1.54	0.615bBA
SA-CJC		6.52 aBA ± 0.11	78.14 aBA ± 1.17	0.399bBA
Raw material		1.05 aAA ± 0.13	89.93 aBA ± 0.92	0.265bAA
SA	F-D	1.34 aAA ± 0.12	87.74 aBA ± 1.54	0.319bAA
SA-CJC		1.22 aAA ± 0.14	87.27 aBA ± 1.43	0.317bAA

C-MVD – convective and microwave-vacuum drying, F-D – freeze-drying. Other explanations as in Table 1. Homogeneous groups: a, b – kind of fruit; A, B – method of drying; A – osmotic substance.

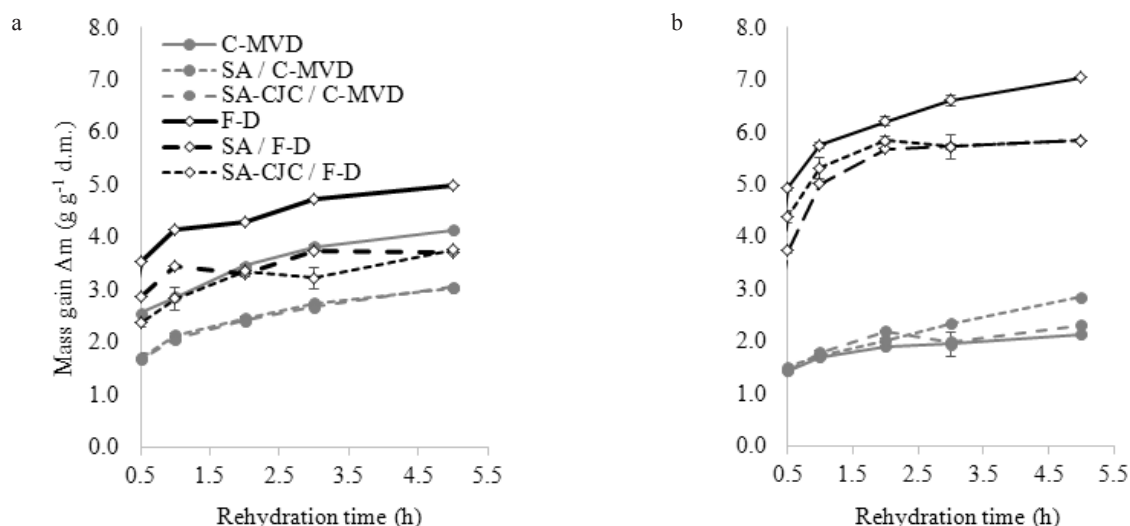


Fig. 1. Kinetics of mass gain during rehydration in dried: a – apples, b – strawberries.

Table 3. Multiple regression of rehydration indicators as a function of process parameters

Rehydration indicators	Slope	Drying methods	Osmotic substance	Time of rehydration	Kind of fruit	Regression coefficient R^2	R^2 (corrected)
Δm	2.048	1.897	-0.387	0.203	0.765	0.630	61.7%
Δs	0.750	0.050	-0.032	0.033	-0.017	0.487	45.9%

Δm – mass gain, Δs – solid loss.

by the convective and ‘puffing’ way (the hybrid approach). Statistical analysis indicated significant differences between the mass gain depending on the raw material, type of osmotic substance, the drying method and the time of rehydration. According to the regression equation (Table 3), mass gain resulted mostly from the drying method applied. The type of fruit, osmotic substance (chokeberry concentrate addition) and the time of rehydration less impacted the mass gain of the rehydrated fruit.

Changure *et al.* (2008) have shown that pre-dehydration hinders the rehydration process because it reduces the number of empty intercellular spaces, and the surface of the cell is coated with an osmo-active substance which creates a barrier to water penetration. Moreover, the method of drying changes the structure of fruit cells, which affects the dynamics and the hydration effect. The method of drying turned out to be dominant and it irreversibly changed the structure of the dried fruit. The indicated effect was even more pronounced in strawberries. A 2-3 times bigger mass gain was noted in freeze-dried fruit when compared with the hybrid (convective and microwave-vacuum) dried one. The said effect was maintained for almost the entire duration of the experiment. In the case of dried strawberry fruit, the differences between the mass gain depending on the type of osmotic substance used in the pre-dehydration were very similar. Slow rehydration is desired when complex mixtures of products with different reconstitution dynamics (such as

muesli) are brought together. Therefore, by using an appropriate osmotic substance and drying method, it is possible to obtain a rehydrated product with the desired organoleptic characteristics. Maldonado *et al.* (2010) revealed that the rehydration kinetics of mango was not affected by osmo-dehydration pretreatments in sucrose, but the pretreatment in glucose significantly improved rehydration.

During the rehydration (Fig. 2) of dried fruit without osmo-pretreatment, in comparison to with it, solid loss (Δs) was slightly higher. However, no big impact of the type of fruit and osmotic substance on the solid loss was observed during the rehydration of dried apples. Still, significant differences were identified in the case of the control test and the fruit dehydrated in a sucrose solution with chokeberry concentrate addition. It was demonstrated that the method of drying and the time of rehydration exert significant effect on solid loss. However, the indicator in dried apples changed to quite a small extent during the whole measurement scope, whereas in the case of freeze-dried strawberries, solid loss was even 2-times higher when compared to rehydration of ‘puffed’ dried fruit. The regression equation (Table 3) indicates that the solid loss was the greatest extent affected by the drying method. The exerted time of rehydration, osmotic substance and type of material held smaller impacts.

Osmotic dehydration as pretreatment can enhance natural flavour and colour, as well as generate softer textures in fruit products (Akbarian *et al.*, 2014). It was noted that the

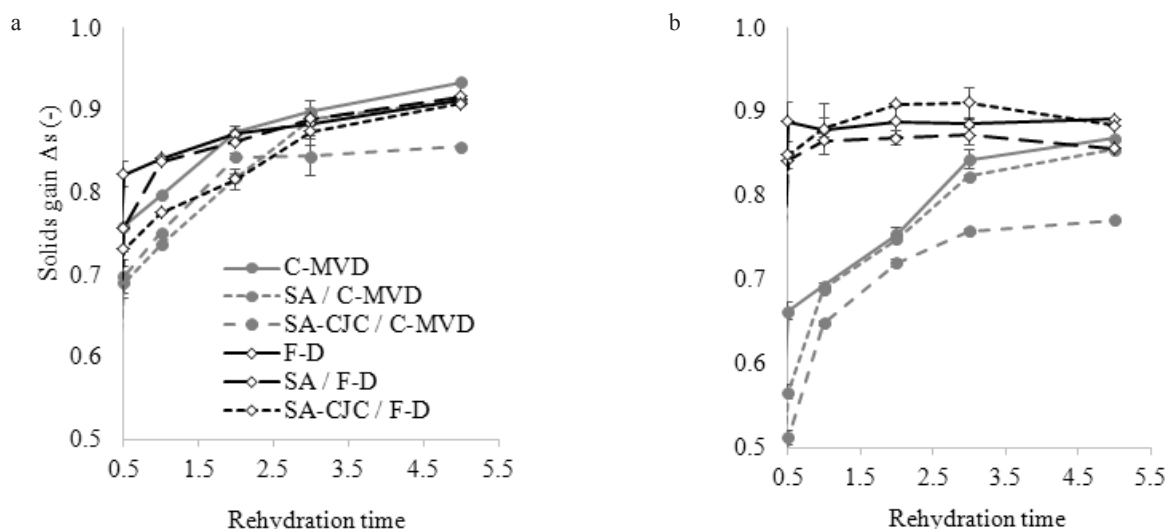


Fig. 2. Kinetics of solid loss during rehydration in dried: a – apples, b – strawberries.

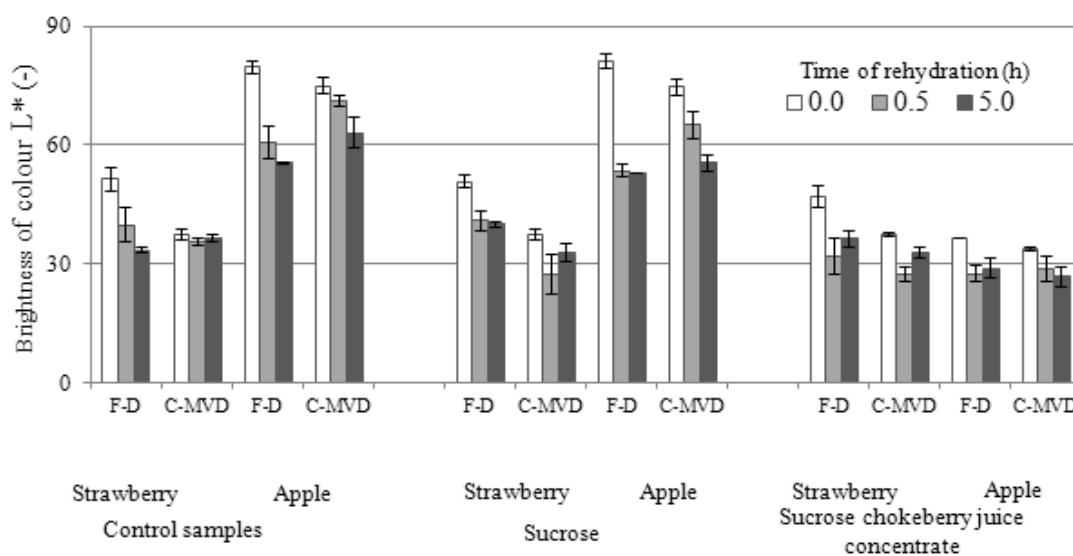


Fig. 3. Effect of osmotic dehydration, drying methods and rehydration on brightness L^* of rehydration dried fruit.

osmotic pre-treatment and drying methods greatly affected the brightness of colour of the dried apples and strawberries before and after rehydration (Fig. 3). Higher values ranging from 71.0 to 81.1 were displayed by the dried apple fruit, particularly the product without the pre-dehydration or the one dehydrated in the sucrose solution. Lower values ranging from 37.4 to 51.5 were observed in control samples of the strawberries dried fruit and the dried fruit dehydrated in the sucrose solution. The lowest brightness was obtained in the dried fruit pre-dehydrated in the sucrose with chokeberry juice concentrate solution (SA-CJC). This was due to the penetration of the chokeberry concentrate ingredients into fruits. Still, in some cases, the dried fruit subjected to a long lasting rehydration turned out to be lighter. This effect is probably associated with the leaching of dyes (osmo-active

substance) to water. The rehydration of control samples and dried fruit pre-dehydrated in sucrose solution induced their darkening. The brightness of colour L^* of the dried fruit after rehydration ranged from 52.9 to 71.0 (apple) and from 27.3 to 40.9 (strawberry). As a result of rehydration, the brightness of colour of the dried fruits pre-dehydrated in the sucrose with chokeberry juice concentrate (SA-CJC) solution saw smaller changes, and ranged from 26.7 to 36.2. In addition, we observed that the drying of raw apples by the C-MVD method or dehydrating them in the sucrose solution before drying brought smaller changes in brightness than in the case of the freeze-dried fruits. Rehydration also did not lead to significant degradation of the substance colour (for example, the anthocyanins) in blueberry fruits (Paławska *et al.*, 2010) and other plant tissue.

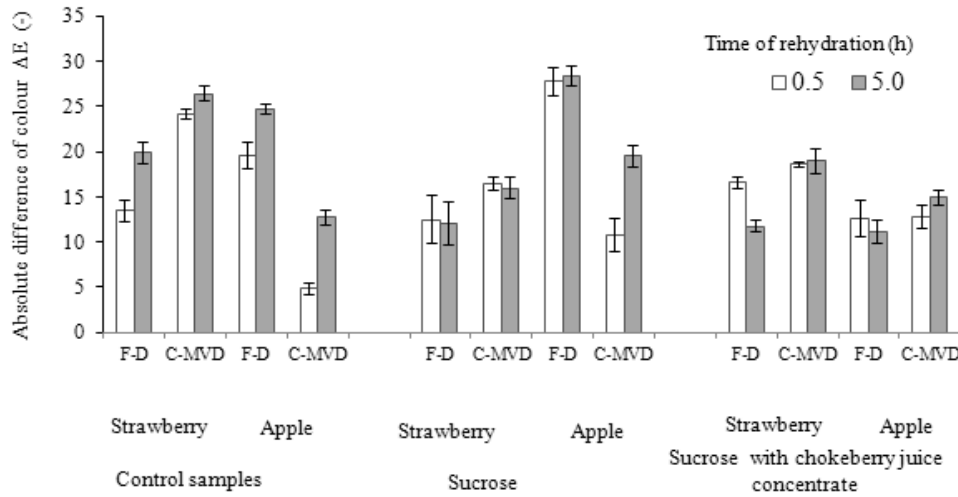


Fig. 4. Effect of osmotic dehydration, drying methods and rehydration on absolute difference of colour DE of rehydration dried fruit.

Rehydration resulted in significant changes of absolute difference of colour ΔE of the dried fruits, in comparison with the samples before rehydration (Fig. 4). Due to the specific colour of dried apples, greater changes have occurred in these droughts. The methods of drying and time of rehydration had not a significant effect on the colour change of droughts. We did observe, however, that in the case of the control samples (without prior osmotic dehydration), a longer time rehydration from 0.5 to 5 h induced a greater change in the colour of the apples and strawberries, but when the samples were osmo-dehydrated in a sucrose solution or in sucrose with chokeberry juice concentrate, the absolute differences of colour varied. Moreover, in most of the samples, preliminary dehydration brought about a reduction in discoloration of drought during rehydration.

In order to find similarities and differences between the analysed types of dried fruits in the aspect of the evaluated osmotic dehydration, drying methods, colour parameters and correlations between them, a principal component analysis (PCA) with classification was conducted, taking into account mean values of individual parameters. By using the sufficient proportion criterion and Kaiser's criterion (Stanisz, 2011), the number of the analysed variables was reduced to two principal components (PC1 and PC2). The selected components PC1 and PC2 explained 72.5% of the variability of the rehydration properties of dried fruits (Fig. 5a) with simultaneous 27.5% loss of information. The first component (PC1) included the osmotic dehydration and drying methods parameters, whereas the second principal component (PC2) was constituted by rehydration

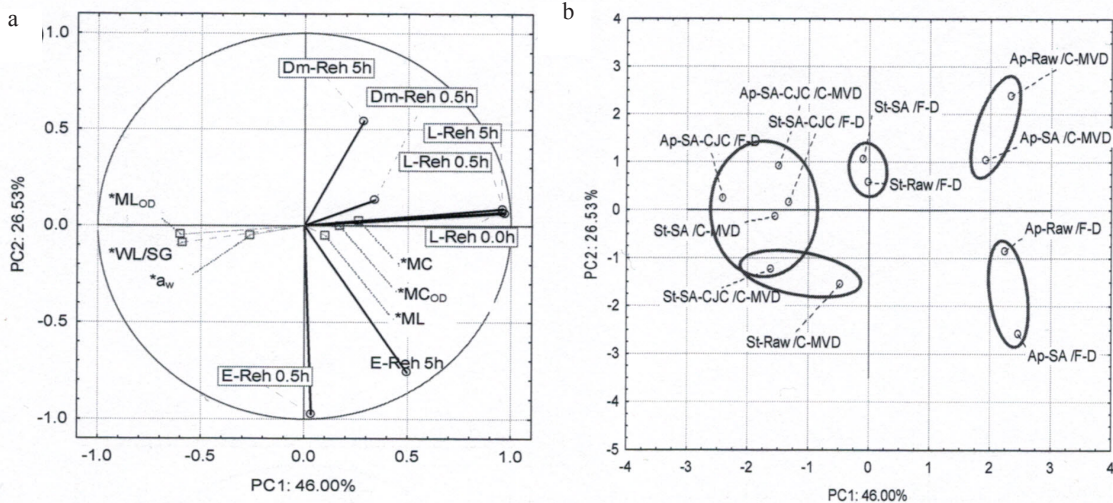


Fig. 5. PCA analysis: a) diagram PCA, b) projection of differences and similarities (Ap – apples, St – strawberries, Raw – no osmotic dehydration droughts, SA – osmotic dehydration in sucrose, SA-CJC – osmotic dehydration in sucrose with cranberry juice concentration, ML_{OD} – mass loss during osmotic dehydration, C-MVD – convective-microwave – vacuum drying, F-D – freeze drying, Reh – rehydration, Dm-Reh – mass gain, L-Reh – brightness of colour, E-Reh – absolute difference of colour).

parameters and colour changes. A greater degree of osmotic dehydration of fruits expressed by mass loss (ML_{OD}), and the ratio of water loss to solids gain (WL/SG) generated less drying effect – expressed by mass loss (ML) and moisture content (MC). These indicators also have influence upon the colour change of the dried fruits during rehydration. Furthermore, they have an effect upon the colour change of the dried fruits during rehydration. The dependence was, however, reversed, *i.e.* the greater dehydration of fruits resulted in a greater darkening of their colour. While the water activity of fruit droughts were highly correlated with osmotic dehydration parameters, simultaneously, prior osmotic treatment before drying did not affect the absolute difference of colour of the samples after rehydration. The date groups of raw and osmo-dehydrated in sucrose solution of apples and strawberries that were then dried by either of two methods (hybrid and freeze-drying) and subsequently rehydrated were located on two similar parts of the diagram (Fig. 5b). For both dried fruits, the rehydration parameters were similarly dependent upon the osmotic dehydration with added chokeberry juice concentrate, and upon the applied drying method.

CONCLUSIONS

1. The addition of chokeberry juice concentrate to the sucrose solution had a significant effect on the mass transfer during the osmotic dehydration of apples and strawberries. The chokeberry juice concentrate generated a greater mass loss of fruit by 7-8%, compared to the osmotic solution without it. Furthermore, in strawberries an even 3-times higher effect of dehydration (water loss/solids gain ratio) than that of apples was demonstrated.

2. The application of the type of tissue and osmotic solution, as well as method of drying had a significant influence on the properties of the resulting dried fruit. Convective drying with a ‘puffing’ effect (the hybrid approach) of osmotically dehydrated apples revealed a significant mass loss (about 70%), but the loss was slightly smaller than in the case of the freeze-dried fruit (approximately 80%), while in the case of strawberries, the same figure was, respectively, 80 and 90%.

3. The application of convective drying with a ‘puffing’ effect after osmotic pre-treatment resulted in the production of dried fruit with similar properties to those obtained by the freeze-drying, which is regarded as a comparative method.

4. The freeze-dried apple rehydration, with regard to mass gain, was slightly higher than in samples dried by convective microwave-vacuum method (the hybrid approach). The freeze-dried strawberries were characterised by a 2-3 times greater capacity to absorb water (higher mass gain), when compared with the dried fruit obtained by the hybrid drying approach (with the ‘puffing’ effect).

5. In the dried fruit rehydration, the drying method was the most important factor with regard to the ability to absorb water. This effect was most evident in the case of dried strawberry rehydration.

6. In the tested rehydrates, the addition of the chokeberry juice concentrate into the solution of sucrose resulted in smaller colour changes.

7. For both dried fruits, the rehydration parameters were similarly dependent on the osmotic dehydration with added chokeberry juice concentrate, and on the drying method applied.

Conflict of Interest: The authors declare that they have no conflict of interest.

Compliance with Ethical Requirements: This study does not contain any experiment involving human or animal subjects.

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